LEVEL III

HUGHES Research Laboratories

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CORRECTION OF PHASE DISTORTIONS BY NONLINEAR OPTICAL TECHNIQUES.

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CONTRACTOR:	Hughes Research Laboratories
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CONTRACT AMOUNT:	$788,907
CONTRACT NO:	N00014-77-C-0593
CONTRACT EXPIRATION DATE:	31 Dec. 1980
SHORT TITLE OF WORK:	Nonlinear Phase Conjugation
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Program Objectives

This continuing program is designed to explore a recently recognized property of nonlinear optical interactions to generate wavefronts that have the unique property of correcting optical distortions in a laser system. These distortions include optical train aberrations, laser medium distortions, and atmospheric propagation aberrations.

Approach

The effort in this program is divided into three tasks. The first task is an experimental effort to explore the physics of phase conjugation via four-wave mixing in the visible with emphasis on the blue-green and ultraviolet region of the spectrum using appropriate dye lasers. Issues such as degree of correction, efficiency, and required pump wave properties will be addressed in this task. In addition, we will determine the efficiency of conjugate wave generation as a function of detuning of the pump frequency from the probe frequency a concept which has direct impact on systems concepts. The second task concentrates on expanding our understanding of the theory of four-wave mixing with emphasis on the pump manipulation and polarization rotation issues and on those features that maximize the efficiency of the process, such as resonant enhancement. In addition, on this task we will select material candidates that show promise for high-power application in the blue-green and UV. The third task will concentrate on the systems-related issues of nonlinear phase conjugation with emphasis on systems of interest to DARPA. We will expand our analysis of the concepts generated and generate new concepts. We will also identify critical technologies for high-power application of nonlinear phase conjugation to DARPA systems.

Major Accomplishments

We have addressed issues in each of the above task areas. A briefing to summarize these results was presented at DARPA in October.

We have performed preliminary dual wavelength DFWM experiments, shown that two separate lasers can be employed, one for pump, one for probe, and still generate a DFWM signal, performed measurements of the degree of conjugation at high DFWM reflectivities; extended our DFWM theory to include pump absorption and coupling of all four waves; and performed detailed tradeoff studies of amplifier gain-conjugator reflectivity-energy extraction for candidate uplink or oscillator system configurations.

A more detailed discussion of these results is given in the package presented to DARPA and inclusion of this package forms the body of this quarterly report.

CORRECTION OF PHASE DISTORTIONS BY NONLINEAR OPTICAL TECHNIQUES

STATUS AND RECOMMENDATIONS

OCTOBER 1980

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TECHNICAL EMPHASIS DURING CURRENT PHASE (6/80-12/80)

DEGENERATE FOUR WAVE MIXING (DFWM) EXPERIMENTS IN THE GREEN AND BLUE-GREEN

- DOUBLED YAG AND YAG-PUMPED DYE LASERS
- DUAL WAVELENGTH DFWM
- PUMP/PROBE COHERENCE EXPERIMENTS
- CONJUGATION FIDELITY AT HIGH REFLECTIVITIES

DFWM CALCULATIONS

- EXTENSION OF THEORY TO INCLUDE PUMP ATTENUATION
- EXTENSION OF THEORY TO INCLUDE FULL COUPLING OF ALL FOUR WAVES

ANALYSIS OF SYSTEMS EMPLOYING OPTICAL CONJUGATORS

- UPLINK SYSTEMS EMPHASIS
- BEACON VS RETRO OPERATION
- AMPLIFIER GAIN/CONJUGATOR REFLECTIVITY/ENERGY EXTRACTION TRADEOFFS

RELATED PROGRAMS

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9392-98

- HUGHES IR&D (1980)
  PHYSICS OF PHASE CONJUGATION
  THEORY OF OPTICAL RESONATORS WITH PHASE CONJUGATE MIRRORS
  HIGH BRIGHTNESS TACTICAL LASERS (1 μm)
  NEW APPLICATIONS (OPTICAL PROCESSING, ENCODING, DECODING)
  NEW NONLINEAR MATERIALS

- PHASE CONJUGATION FOR FUSION LASERS (LASL)
  SHORT PULSE 10.6 μm PHASE CONJUGATION
  4-WAVE MIXING
  1- AND 2-PHOTON RESONANT ENHANCEMENT

- PHASE CONJUGATE OPTICAL RESONATORS (AFOSR)
  EXPERIMENTAL DEMO OF LOW POWER PULSED PHASE CONJUGATE RESONATOR
  4-WAVE MIXING IN SODIUM VAPOR
  DYE AMPLIFIER

JANUARY 1980

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TWO WAVELENGTH DFWM EXPERIMENTS IN RHODAMINE 6G
USING TWO DIFFERENT LASERS

	RELATIVE SIGNAL		
WAVELENGTH, NM	532	519.5	BOTH
532 (DOUBLED YAG)	1	0	1
519.5 (COUMARIN 500)	0	1	1
532 + 519.5	1	1	2

CONCLUSIONS:

- GRATINGS ACT INDEPENDENTLY
- NO "CROSS TALK"

PUMP-PROBE COHERENCE EXPERIMENTS IN RHODAMINE 6G USING TWO DIFFERENT LASERS AT 532 NM

PUMPS	PROBE	RELATIVE SIGNAL
DOUBLED YAG	DOUBLED YAG	1.0
DOUBLED YAG	COUMARIN 500	~0.1*

*HIGHLY VARIABLE, LIMITED BY FREQUENCY STABILITY.

PHASE CONJUGATE REFLECTIVITY
vs.
PUMP INTENSITY - Rb6

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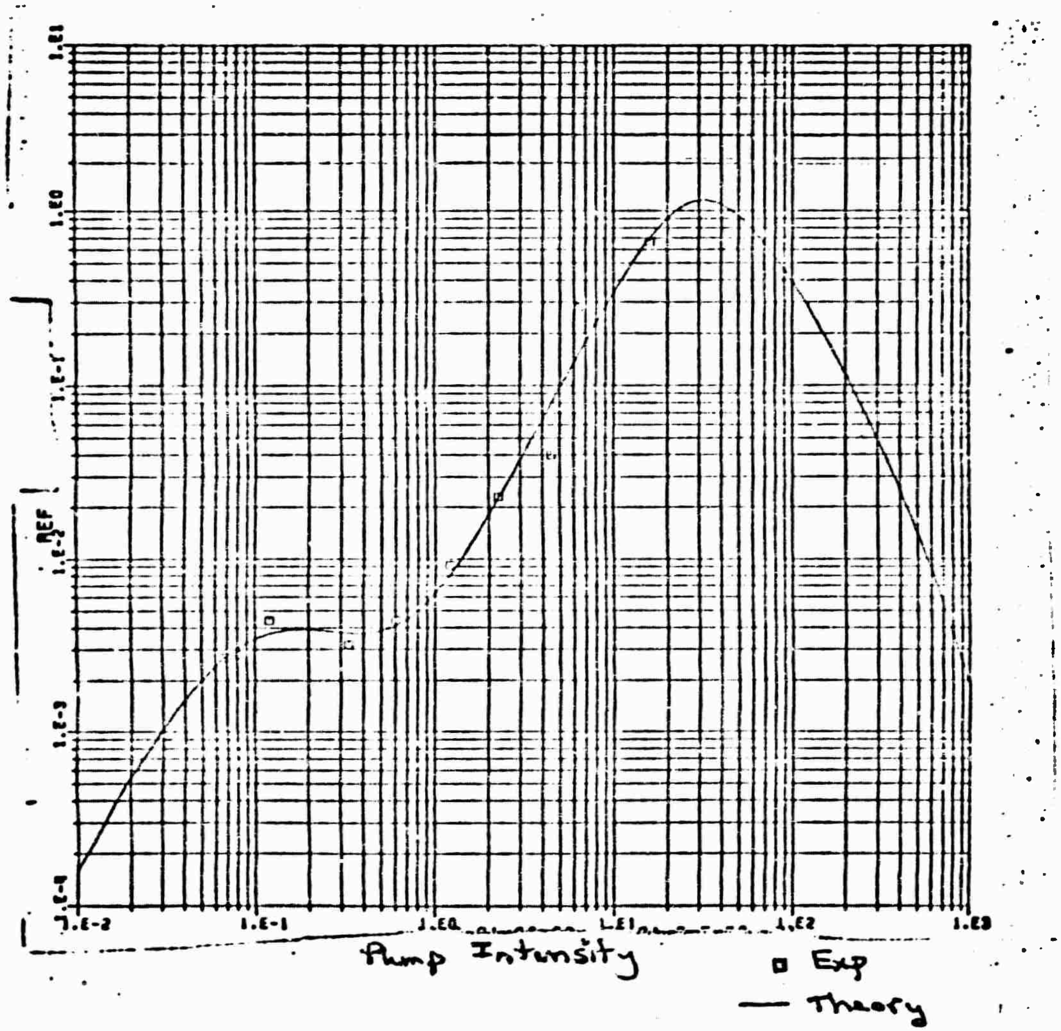

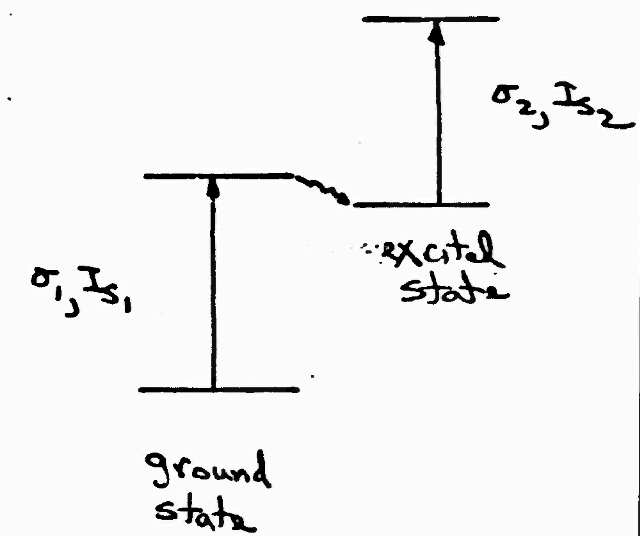

DFWM THEORY

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- Assumptions

  Two–level saturable absorber
  Homogeneous line broadening
  Two–photon effects neglected
  Plane wave analysis

- Results

  Coupled equations satisfied by the pump, probe and signal waves have been derived for both the weak and finite probe limits

  Reflectivity equation derived for the weak probe limit

  Numerical algorithms developed for the solution of the above equations

PUMP ATTENUATION AND DEPLETION EFFECTS ON DFWM

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- Abrams and Lind Theory Assumes Constant Pumps And A Weak Probe(no pump depletion)

  pumps are not attenuated either by absorption or by the nonlinear interaction

- We Have Extended The Abrams And Lind Theory To Account For Pump Attenuation And Depletion

  Weak probe limit: Pump attenuation taken into account but depletion effects are neglected (pump eqs. decoupled from the probe and signal eqs.)

  Finite probe limit: Pump attenuation and depletion are both taken into account (pump, probe and signal eqs. are coupled)

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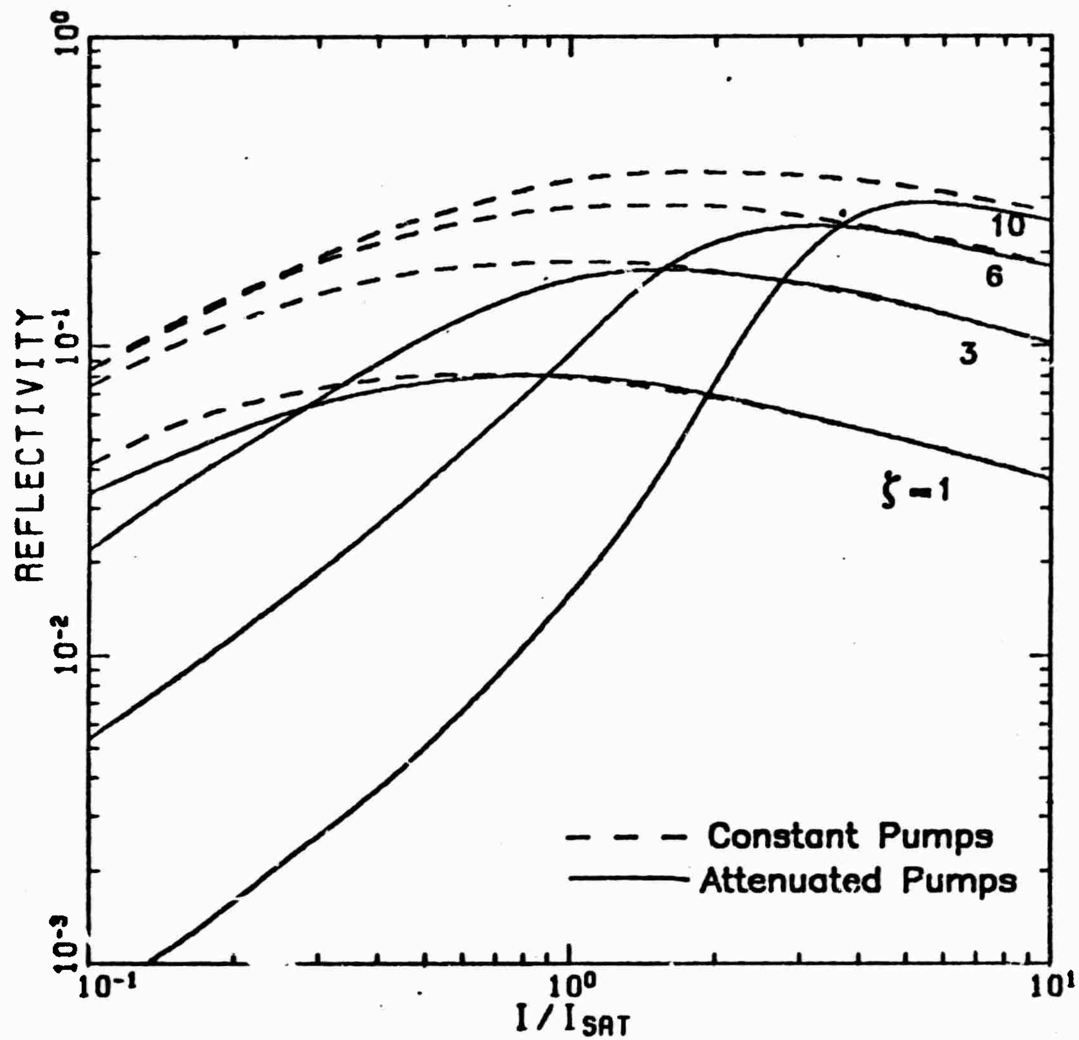
PUMP ATTENUATION EFFECTS ON PROBE WAVE REFLECTIVITY



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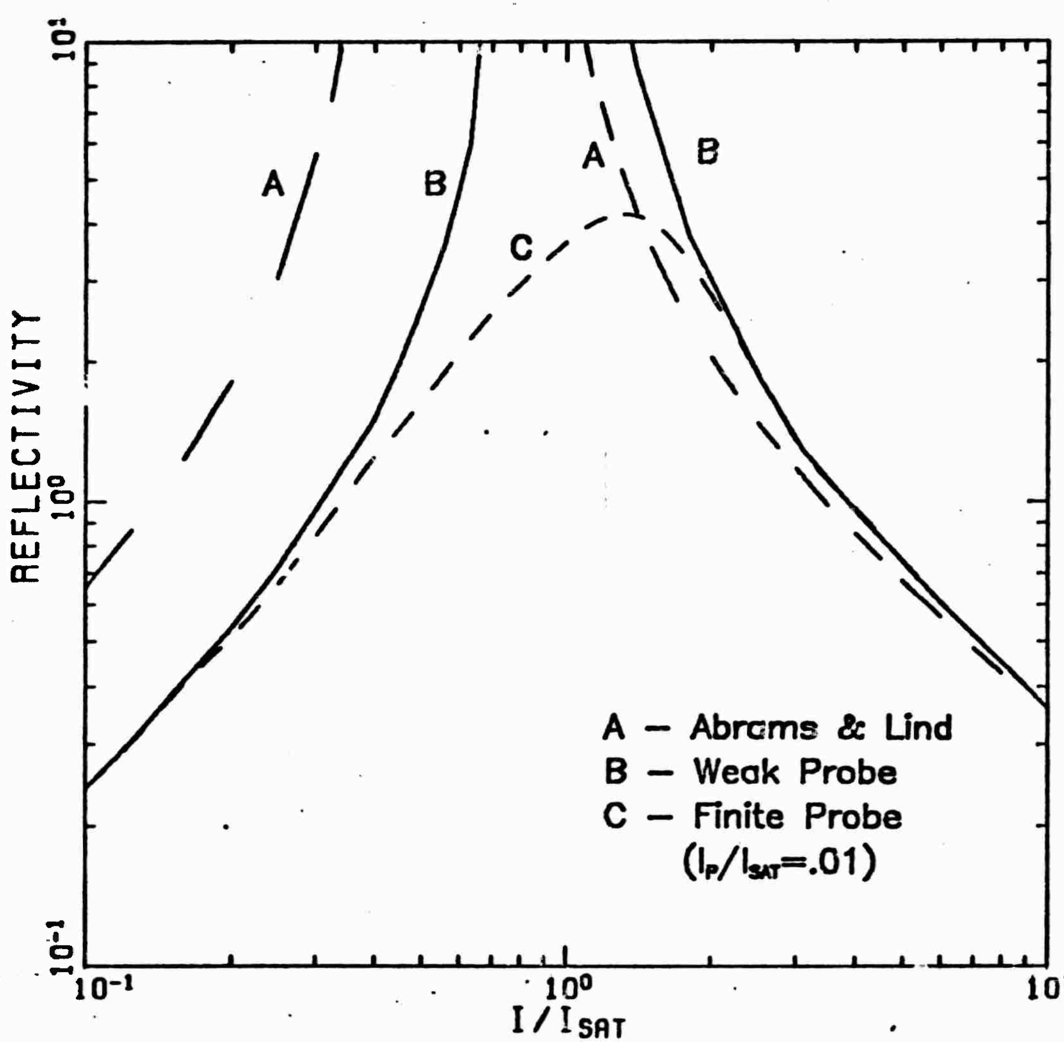
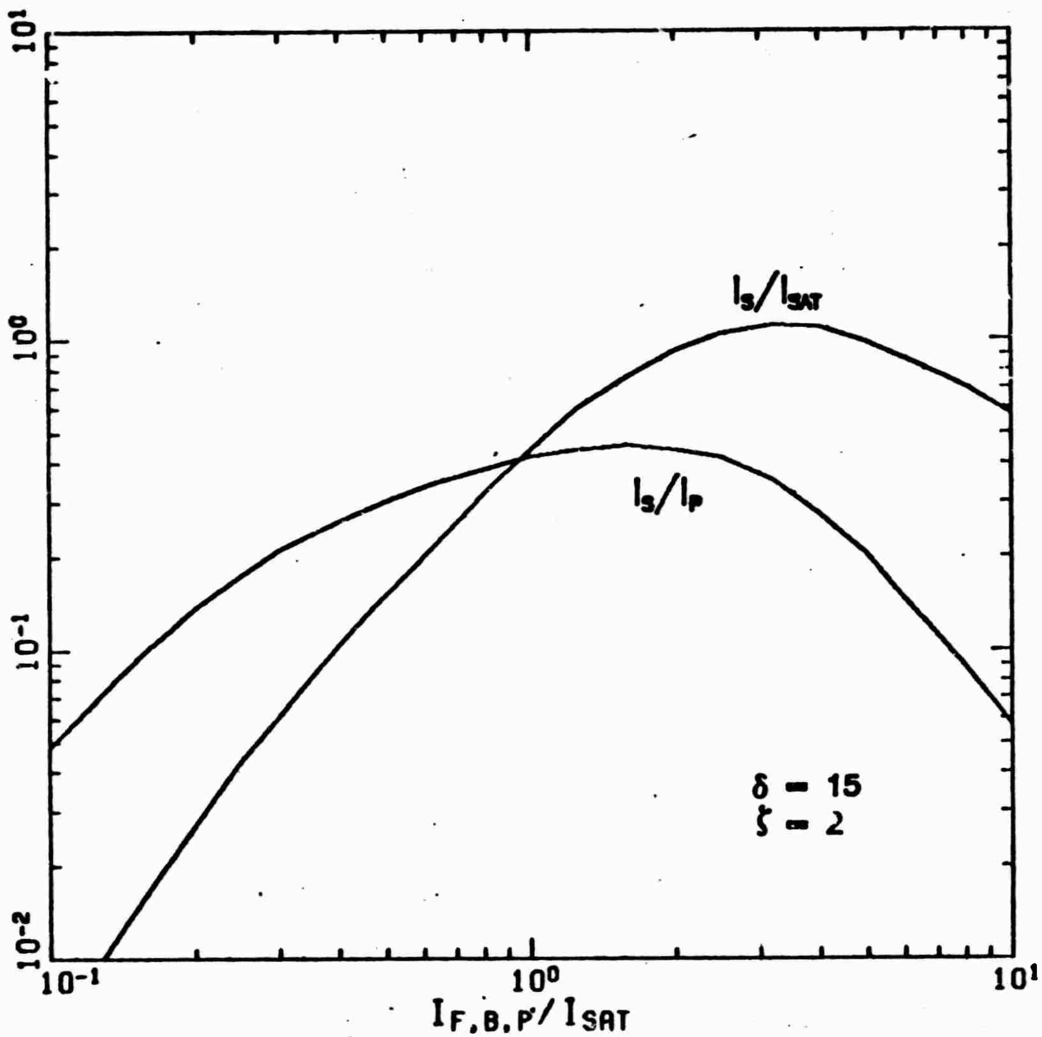
PROBE AMPLITUDE REFLECTIVITY IN THE VICINITY OF A BACKWARD WAVE RESONANCE

$\delta = 15, \ \zeta = 2$



DFWM WITH EQUAL PUMP AND PROBE AMPLITUDES



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OVERVIEW OF NPC
VS ADAPTIVE OPTICS

ADAPTIVE OPTICS (WITH DEFORMABLE MIRRORS) IS EVOLUTIONARY

- CAN BE RETROFITTED OR DESIGNED INTO EXISTING SYSTEMS WITH MINOR PAIN

NON-LINEAR PHASE CONJUGATION IS REVOLUTIONARY

- CANNOT BE SIMPLY RETROFITTTED INTO EXISTING SYSTEMS
- THE CORRECTION POTENTIAL IS SUCH THAT THERE CAN BE A MAJOR IMPACT ON ENTIRE SYSTEM DESIGN

SYSTEMS OVERVIEW

IMPACT OF ORBITS AND DOPPLER SHIFTS

- ORBITAL CHOICE → DOPPLER ⇄ SYSTEM PROBLEMS
- NPC ⇄ BEAM DIRECTOR ⇄ ORBITAL CHOICE
- (STRONG BIAS TOWARDS SYNC ORBITS)
- A CONCRETE BEAM DIRECTOR?

CONJUGATOR QUESTIONS

- DOPPLER ISSUES
- HIGH-POWER CONJUGATOR OPERATION
- FOCUS MANIPULATION VIA PUMPS
- COHERENCE QUESTIONS
- CONJUGATOR APERTURE

GENERAL SYSTEMS ISSUES

- REFERENCE AND TRACKING CHOICES
- GAIN/CONJUGATOR POWER/EFFICIENCY TRADES
- SRS MODELS

SYNCRONOUS/MOLNIYA TRADE OFF WITH NPC

SYNCRONOUS ADVANTAGES

FIXED BEAM DIRECTOR

- LOWER COST
- MORE SYSTEMS ALLOWABLE
- BETTER WEATHER FACTOR
- LARGER BEAM DIRECTOR

FIXED REF SOURCE SPACING

AVOIDS DOPPLER SHIFT QUESTIONS

LOWER RELAY VULNERABILITY

MOLNIYA ADVANTAGES

LESS PATH LOSS (FOR CONUS BASING)

FOR EXAMPLE:
EXTINCTION LOSS* AT SYNC..

1.4DB (θ_z=0°)

4.5DB (θ_z=72°)

*VIA D.P. GREENWOOD
SLC PRES. 27, MARCH 1980
SAMP SYSTEM

THE QUADRA-PETAL MULTI-MIRROR BEAM DIRECTOR

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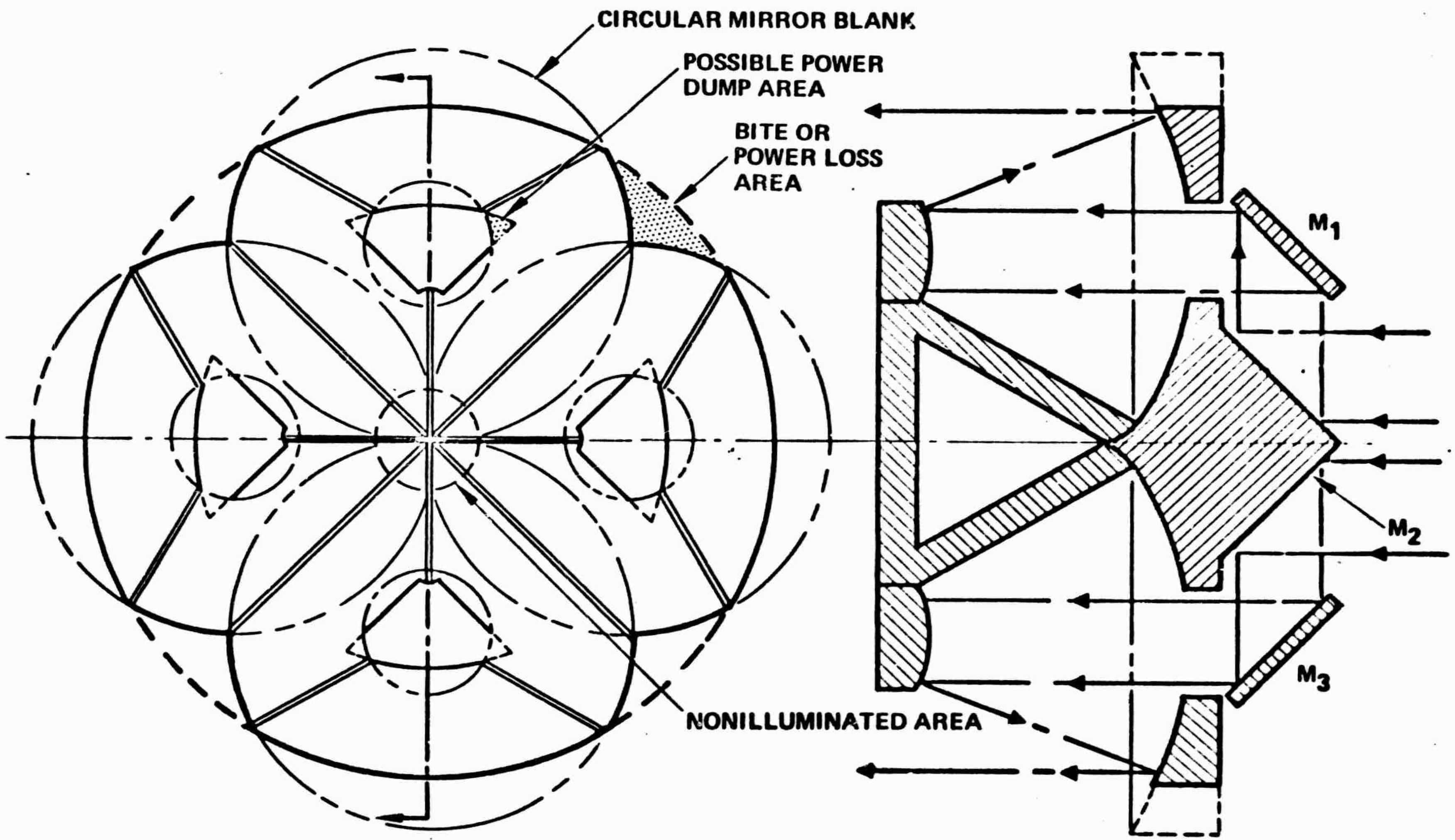

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THE CONCRETE BEAM DIRECTOR

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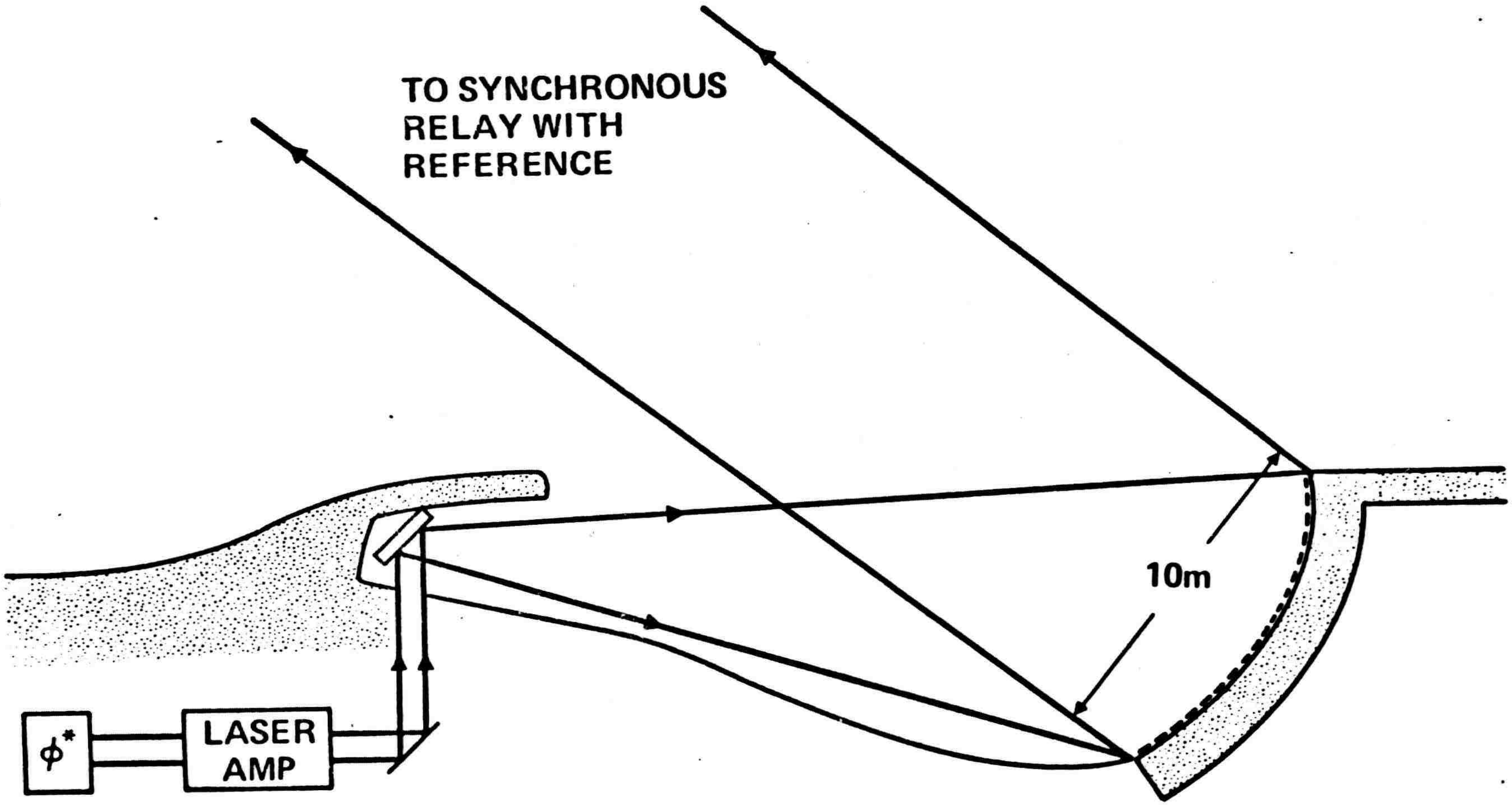

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CONJUGATOR QUESTIONS

- DOPPLER ISSUES
- HIGH-POWER CONJUGATOR OPERATION
- FOCUS MANIPULATION VIA PUMPS
- COHERENCE QUESTIONS
- CONJUGATOR APERTURE

APPROACHES TO THE PUMP-PROBE COHERENCE ISSUE

- STABLE/FREQUENCY-LOCKED LASERS
- SELF-PUMPED DFWM
- 2-PHOTON CONJUGATORS

OFF-CENTER LINE AMPLIFIER OPERATION
CONVERTS AMPLITUDE FLUCTUATIONS TO PHASE

PHASE VARIATION IN A TWO-LEVEL, HOMOGENEOUSLY BROADENED SYSTEM

$$\Delta\phi = \frac{1}{2} g_0 \delta \int_0^L dz \frac{1}{1 + \delta^2 + I(z)/I_{SAT}}$$

δ = DOPPLER OFFSET/NATURAL LINEWIDTH

ASSUME I_{IN} INTO AMPLIFIER HAS FLUCTUATIONS $\sigma \equiv \dfrac{\sigma_{\Delta I_{IN}}}{\langle I_{IN} \rangle}$

DUE TO ATMOSPHERIC SCINTILLATION, FOR EXAMPLE

$$\sigma_{\Delta\phi} \cong \left(\frac{1}{2} g_0 L \delta\right) \left\{ \exp\left[g_0 L/(1+\delta^2)\right] - 1 \right\} \left(\frac{\langle I_{IN} \rangle}{I_{SAT}}\right) \sigma$$

STREHL RATIO = $\exp\left(-\sigma_{\Delta\phi}^2\right)$

STREHL RATIO DUE TO SCINTILLATIONS AND DOPPLER OFFSET

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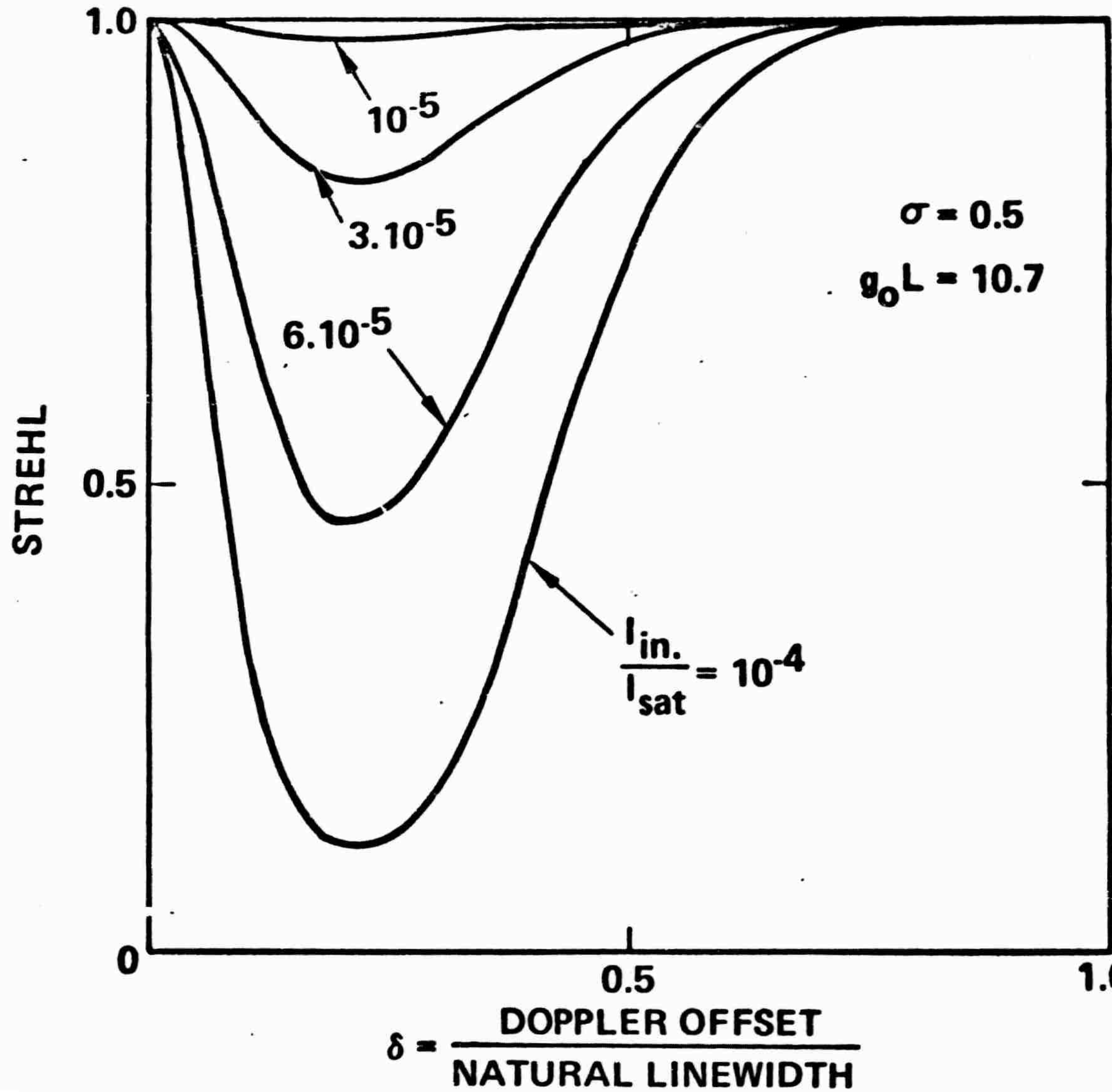

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SELF PUMPED DFWM

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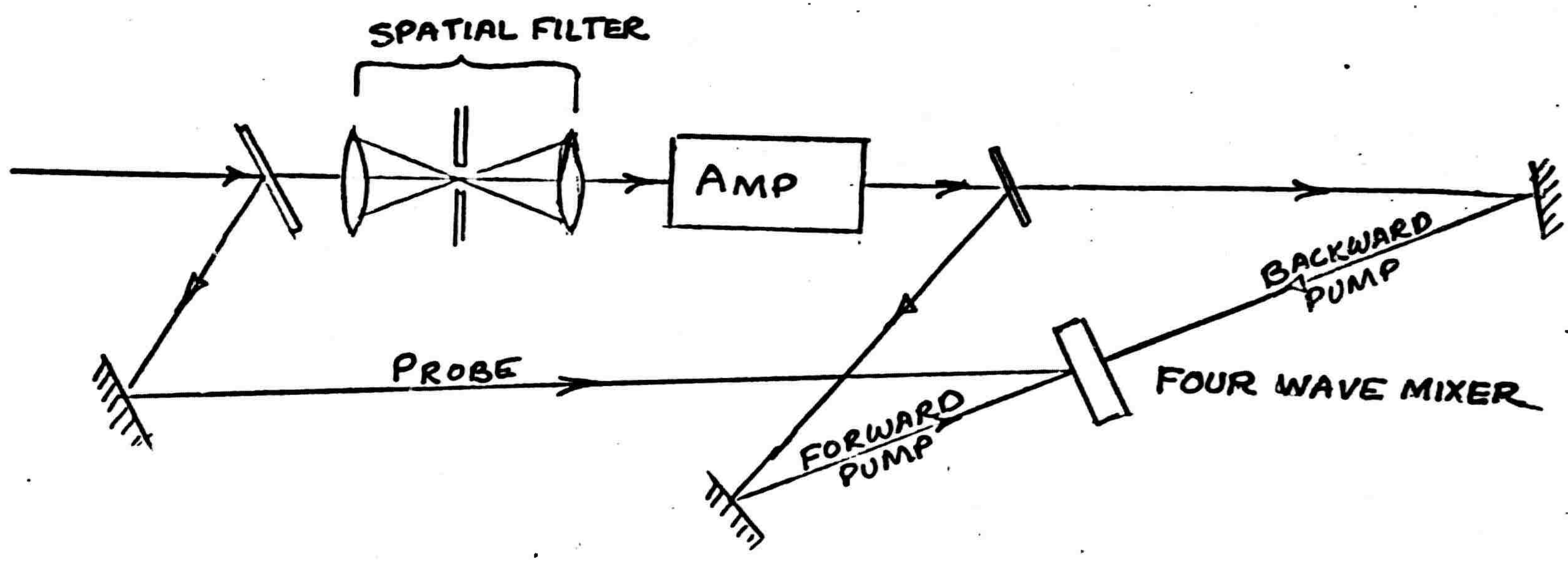

GENERAL SYSTEMS ISSUES:

- REFERENCE AND TRACKING CHOICES
- GAIN/CONJUGATOR POWER/EFFICIENCY TRADES
- SRS MODELS

TWO CLASSES OF REFERENCE/RETRO SYSTEM

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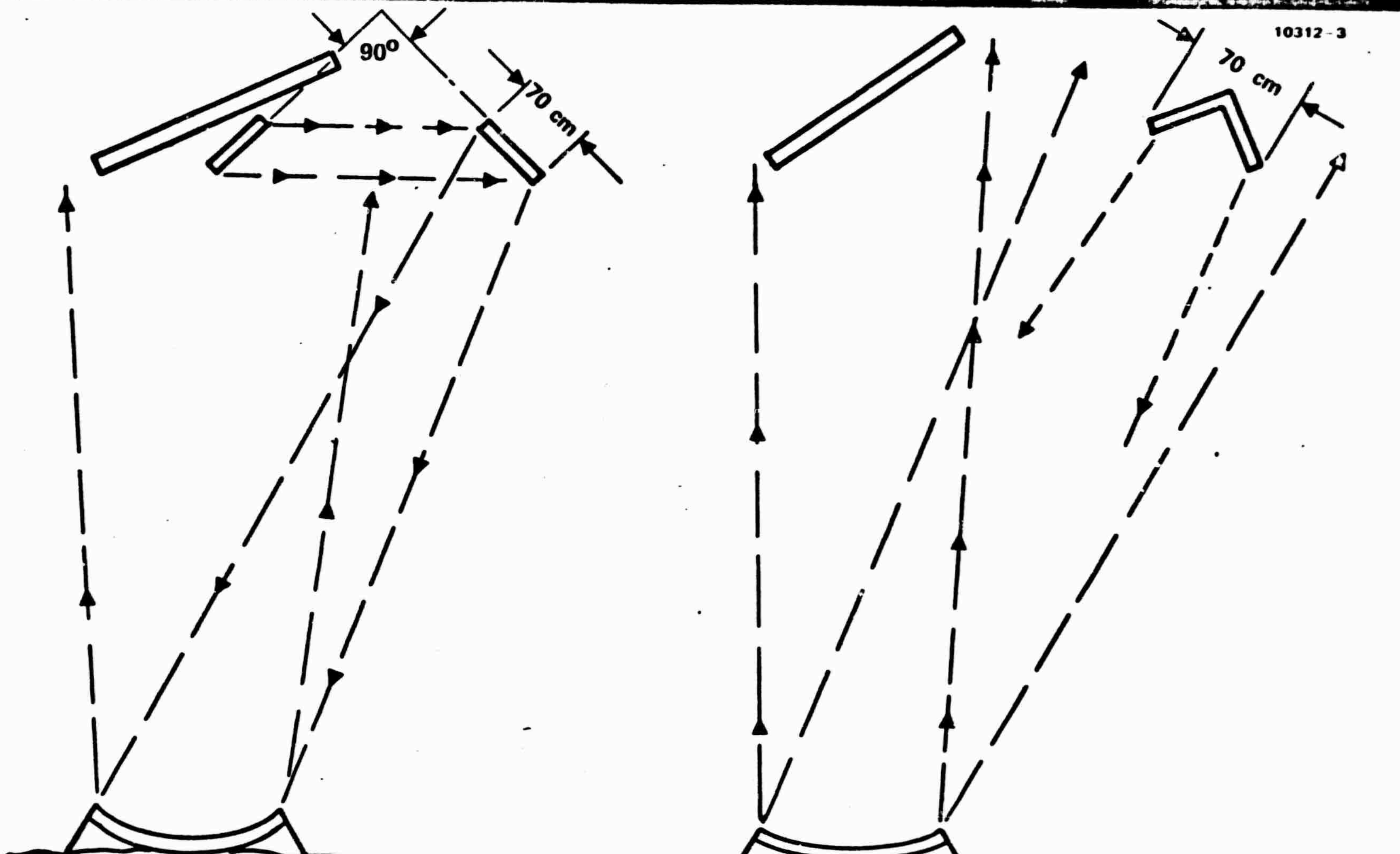

A. THE EXTENDED CORNER REFLECTOR SYSTEM

B. THE FLY AHEAD CORNER WITH OFFSET ILLUMINATOR BEAM

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CONICAL SCAN FOR TRACK AND SPECKLE REDUCTION

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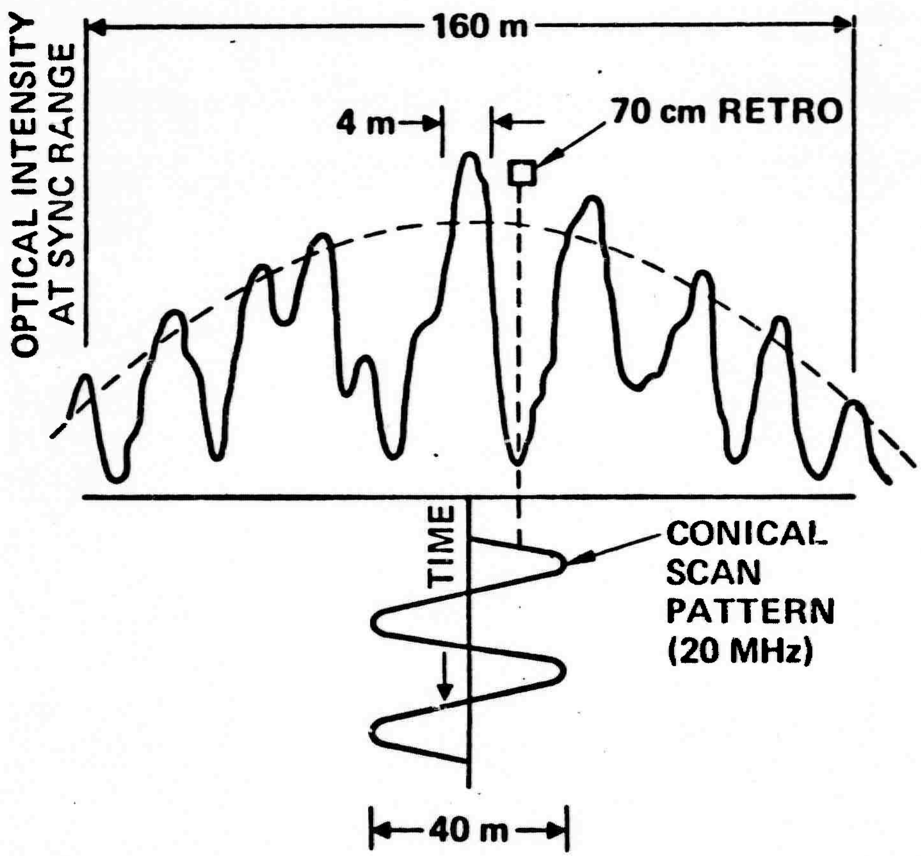

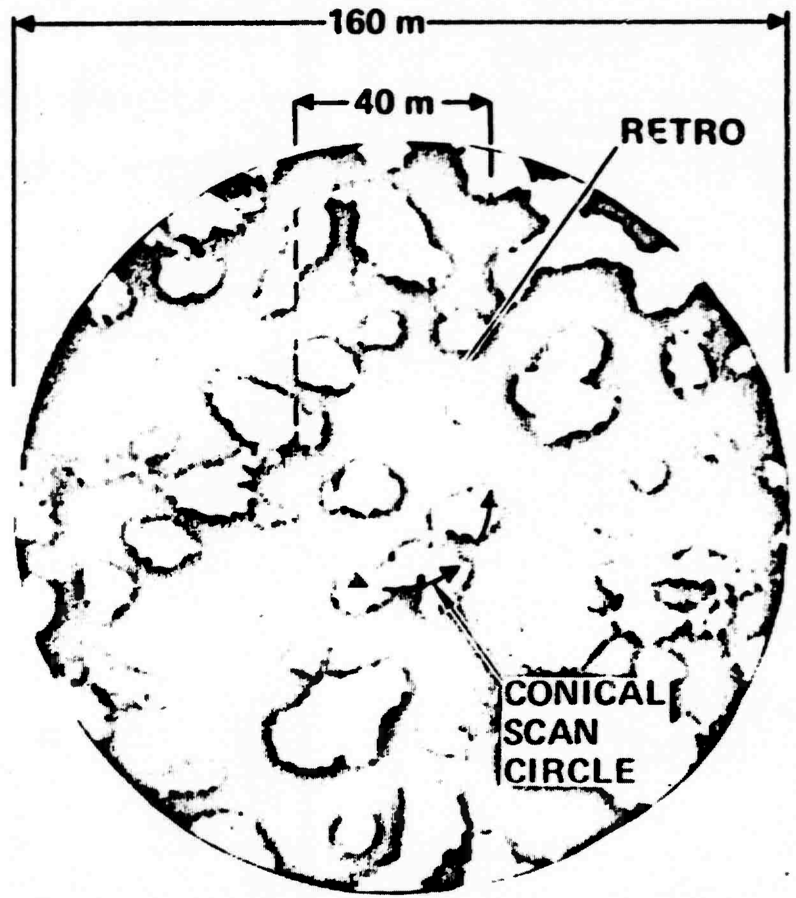

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EFFECT OF SPECKLE ON COMMUNICATION PULSE AMPLITUDE

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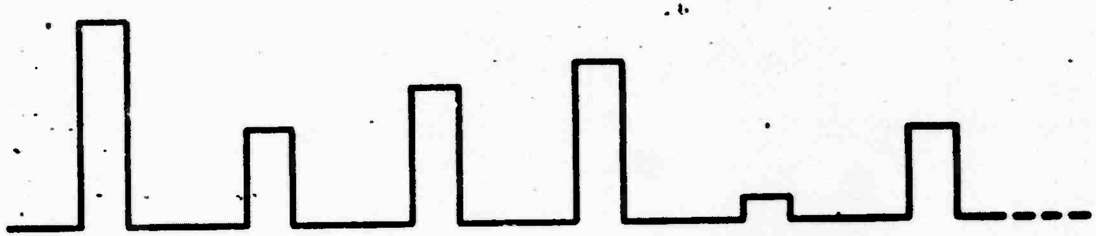
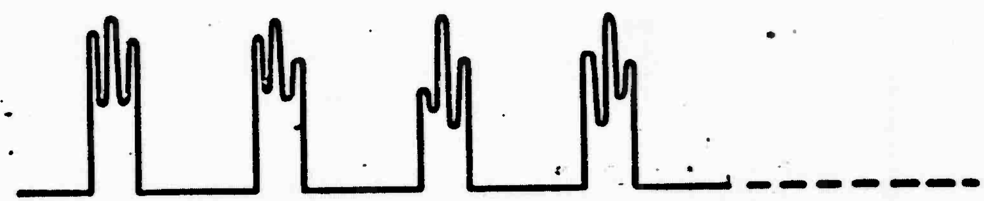


(A) WITHOUT CONICAL-SCAN AVERAGING



(B) WITH HIGH-SPEED CONICAL-SCAN MODULATION "AVERAGING"

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MINI PROGRAM SERIES
TO EXPLORE SATURATION EFFECTS

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<u>COMMON FEATURES</u>

ONE DIMENSIONAL

UP TO THREE AMPS WITH STAGING

SATURATION EFFECTS INCLUDED

AMPLIFIERS: NOW

CONJUGATORS: SOON

ITERATIVE OR LIMITED NO. PASSES

ASSUMES BEAMS OF UNIFORM CROSS-SECTION

SIMPLE 2 LEVEL LASER MODELS

SYSTEMS APPLICABILITY

	SHORT PULSE	CW
ONE-WAY GAIN		OSCILLATORS WITH TWO SBS MIRRORS
TWO-WAY GAIN	LASER COUNTER MEASURES	BLUE GREEN COMMUNICATION SYSTEMS

EXTRACTION EFFICIENCY vs GAIN FOR UNIFORM CROSS SECTION LASERS

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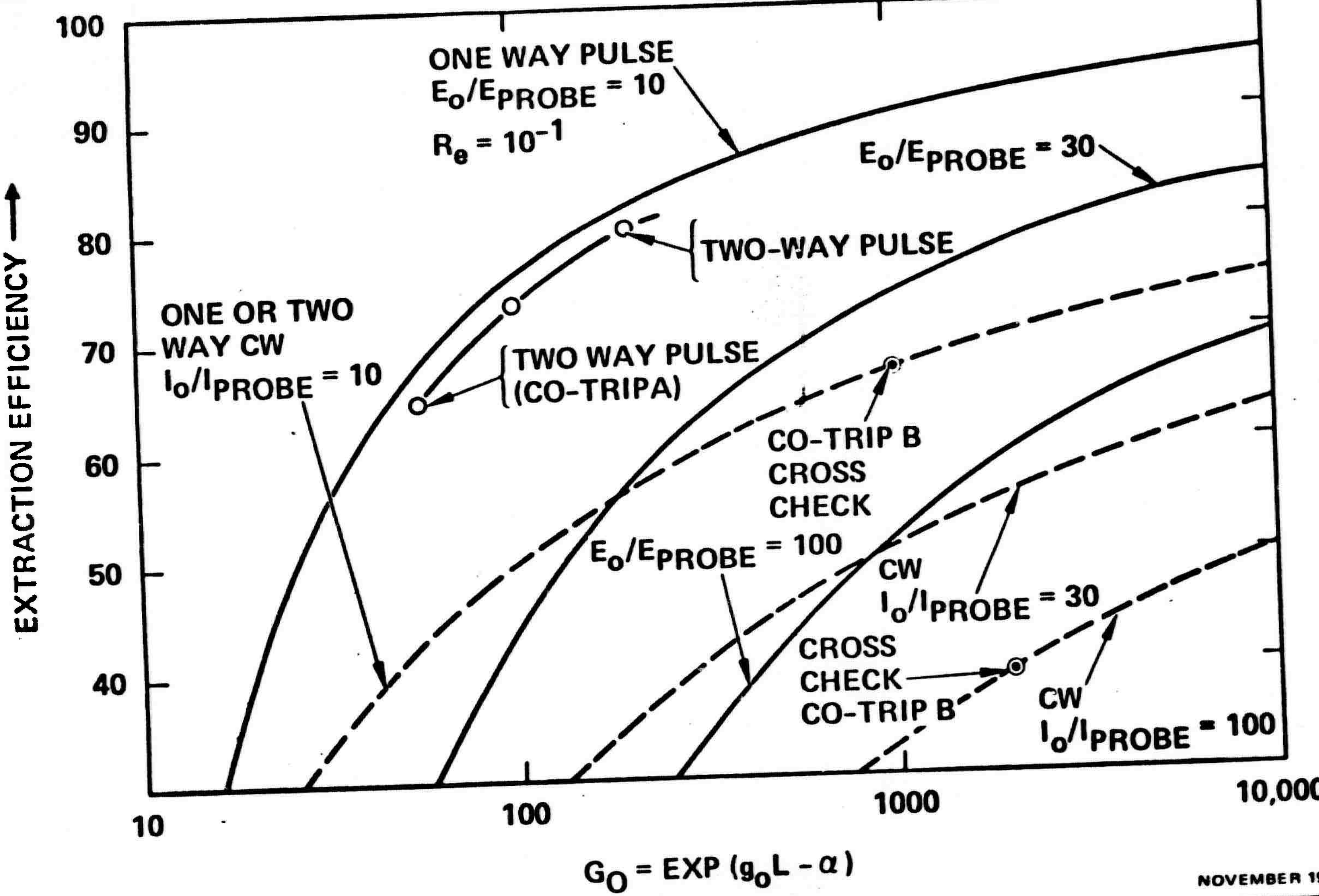

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GAIN/CONJUGATOR-POWER/EFFICIENCY TRADES

BACKGROUND

ASSUME STANDARD CW OR PULSE "2 LEVEL" GAIN MODELS ON RESONANCE

BOTH STANDARD ANALYSIS AND MINI CODES

CONCLUSIONS OVERVIEW

HIGH GAINS ARE REQUIRED (35 x 35 x 35) TO ACHIEVE GOOD EXTRACTION EFFICIENCY (55%)

PULSE POSITION MODULATION IS COSTLY IN TERMS OF REQUIRED GAIN (BECAUSE OF WEAK REF)

STAGING OF BEAM EXPANSION IS HELPFUL (1.5 EXPANSION ABOUT OPTIMAL)

CONJUGATOR PROBE/PUMP POWER LEVELS ARE NOT A NEGLIGIBLE PROBLEM (684W & 205/PULSE)

EQUAL PROBE POWER LEVEL REGIMES NEED DETAILED EXPLORATION

RETRO-REFERENCE CANDIDATE UPLINK SYSTEM CONCEPT

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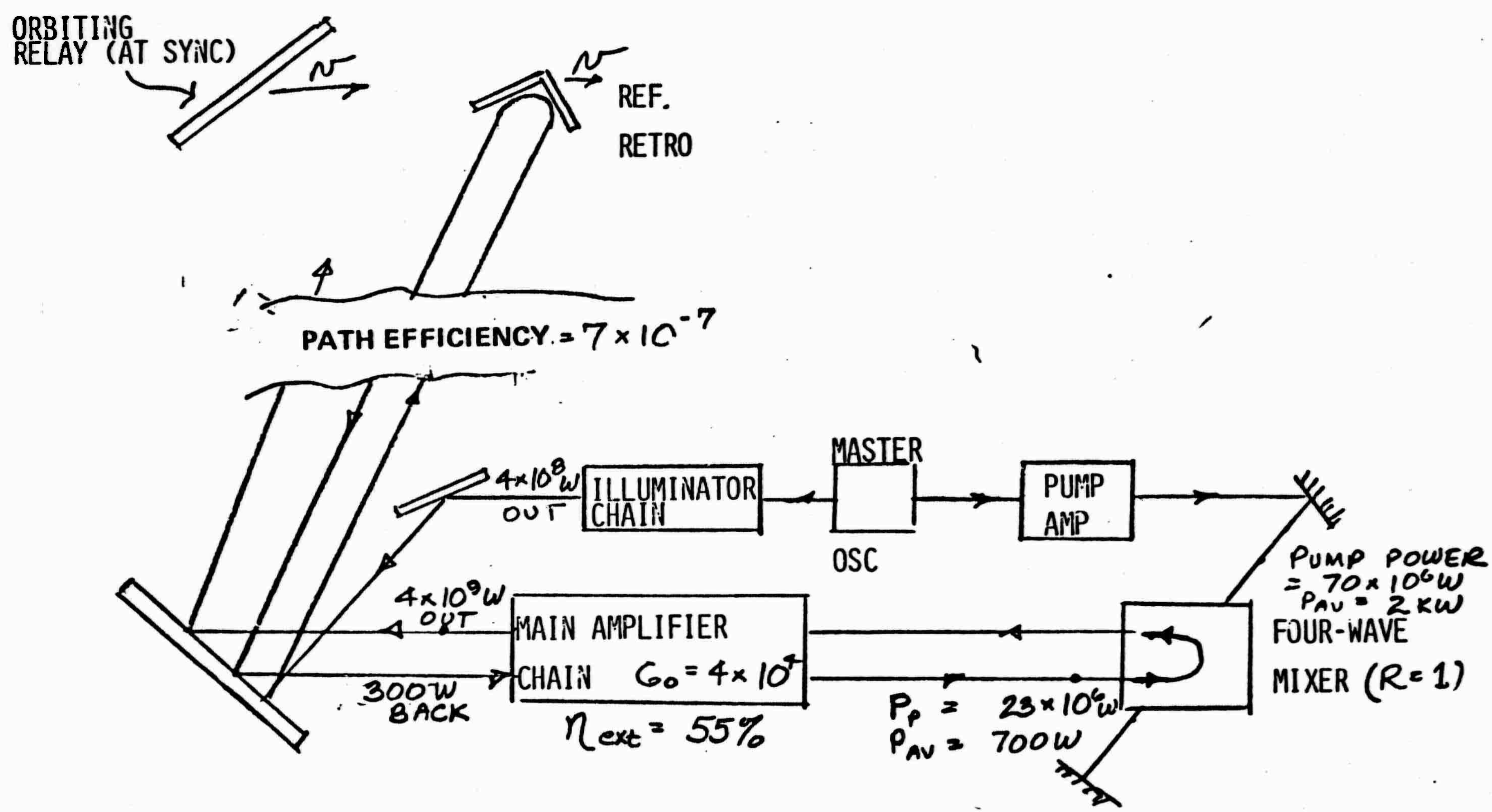

BASELINE COMMUNICATION SYSTEM TO SYNCHRONOUS ORBIT WITH NONLINEAR PHASE COMPENSATION

BEAM DIRECTOR

A. 4M MULTIMIRROR ARRAY ON GIMBALS

B. 10 METER FIXED DISH ARRAY ON CONCRETE

DUAL LASER ILLUMINATOR (2 PULSE SYSTEM)

REF ILLUMINATOR

- o SETS TIMING FOR PULSE POSITION MODULATION
- o TRIPLE AMPLIFIER CHAIN: G_0 (PERSTAGE) = 10
- o 1.5X BEAM EXPANSION BETWEEN STAGES

MAIN ILLUMINATOR

- o TRIPLE AMPLIFIER CHAIN
- o G_0 (PERSTAGE) - 35
- o 1.5X BEAM EXPANSION BETWEEN STAGES
- o EXTRACTION EFFICIENCY ~55% (3 STAGES)

BASELINE COMMUNICATION SYSTEM TO SYNCHRONOUS ORBIT WITH NONLINEAR PHASE COMPENSATION

REFERENCE

SINGLE 70 CM CORNER AT "POINT-AHEAD" SPACING

CONJUGATOR

- 4WM WITH PUMP OFFSETS FOR SPACING ERROR COMPENSATION
- SIZE: 4CM (PUMP & PROBE)
- POWER:

POINTING/TRACKING

- DUAL CONICAL SCAN

  REF. ILLUM ON REF

  MAIN ILLUM ON RELAY MIRROR

SRS AMP/CONJUGATOR WITH ORBITING OSC

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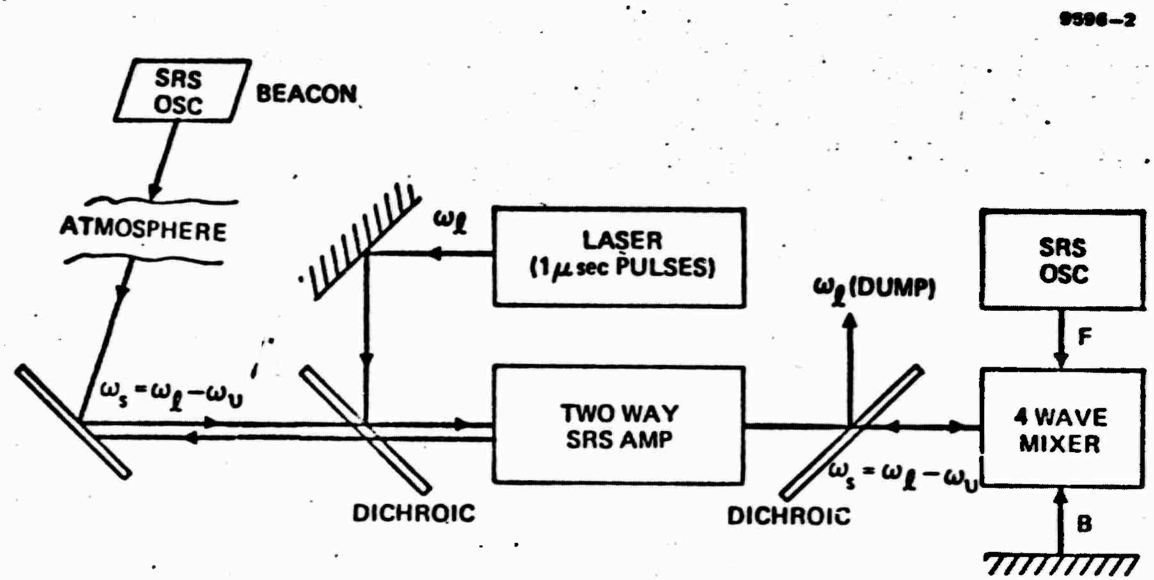

CLASSIFICATION REG. NO. DATE

SRS AMP/CONJUGATOR WITH ORBITING RETRO

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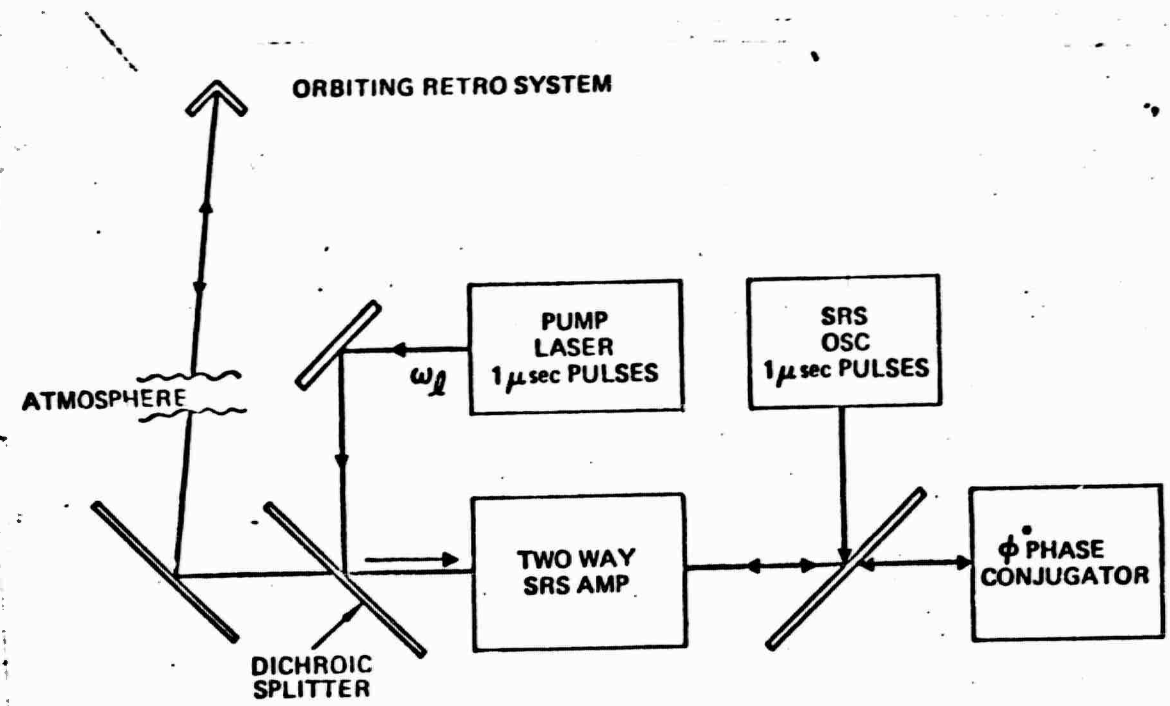

SRS AMPLIFIER WITH PUMP/SIGNAL OFFSET COMP.

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